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Abstract

Bolometric corrections for Ap(Si) (silicon enhanced) stars in open star clusters have been determined using low dispersion IUE ultraviolet spectroscopy. Methods described by North (1981) and Lanz (1984) were applied to Ap(Si) stars and normal A stars, as classified by Abt and collaborators in a series of papers covering several open clusters. Applying the methods to two types of stars in the same cluster provided a differential determination of the bolometric corrections between the stars examined. It was assumed that the extinction corrections will be very similar for both classes of stars.

Final Report

BOLOMETRIC CORRECTIONS FOR Ap(Si) STARS IN OPEN CLUSTERS USING LOW DISPERSION IUE SPECTROSCOPY

Introduction

The chemically peculiar A stars, i.e., the Ap stars, exhibit photometric differences from chemically normal A stars. This arises from enhanced redistribution of flux from the ultraviolet into the visible due to increased metal line blanketing, leading to a flux distribution in the visible which appears bluer for an Ap star than it should for an A star of the same effective temperature (Leckrone 1973). Therefore, standard photometric color indices cannot be used reliably to determine effective temperatures for Ap stars.

Lanz (1984) and North (1981) attempted to overcome the problem by determining the bolometric corrections for these stars by making use of ultraviolet spectroscopy in conjunction with Geneva photometry and model stellar atmospheres. With these they determined semi-empirical flux distributions for the Ap and Bp stars in their studies, which were used in calculating the bolometric corrections. Using these types of corrections, one can then make reasonable temperature estimates using photometry in the visible. Both of these studies indicated that bolometric corrections for the Ap stars will typically run approximately 0.2 mag higher than for normal A stars of the same type.

A particularly important question to answer concerns the evolutionary state of the Ap(Si) stars. Can they be zero age main sequence stars or are they confined to more evolved configurations? Comparison of the distribution of chemically peculiar stars and normal stars in clusters in the HR diagram has been one way to investigate this question. However, these studies have been made using photometry in the visible region. For stars which are distinguished by their unusual opacity, it is clearly preferable to make such comparisons using bolometric magnitudes. In this way, the individual bolometric corrections will lead to improved comparisons and hence better knowledge of

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the evolutionary state of Ap(Si) stars.

A sample of four clusters has been chosen for which spectral classification has been carried out (Abt 1978, Abt and Levato 1977,1978, Abt and Morgan 1972). These studies were undertaken in large measure to provide a systematically coherent set of classifications for use in studies of peculiar stellar spectra, especially in the context of inter-cluster comparisons. These clusters are IC 2602, log age in years 7.1, α Persei, log years 7.4, the Pleiades, log years 7.7, and the Coma cluster, log years 8.8. Among the younger clusters, the ages move along in steps of factors of two, while the oldest is somewhat more than 10 times older than the Pleiades. This spread in ages provides a fine mesh in time steps to determine if there are any rapid evolutionary effects leading to the Ap(Si) phemomenon as well as a coarser mesh size if any such evolutionary effects operate over longer time scales.

Scientific Objectives

Bolometric corrections still provide one of the most useful means of estimating the total flux of a star because it provides a means whereby very easily obtained observational quantities, i.e., ground based optical magnitudes and colors, can be employed for that purpose. Accurate bolometric corrections will make the determinations of Ap star effective temperatures more reliable. This, in turn, contributes to the reliability of the determination of other stellar quantities of interest, such as the size and mass of these stars.

This type of study has not been been carried out for stars in open clusters. Studying the problem in this context reduces certain difficulties pertaining to the determination of bolometric corrections for Ap stars. First, this study was limited to Ap(Si) stars, reducing the chances of undesired flux "enhancements" from dim companions, which are known to be ubiquitous with the Hg-Mn stars and the Am stars. Second, extinction in the ultraviolet should be very similar for the stars in the cluster. Third, fluxes will be very comparable because of the very similar distances among the stars involved in the study. Fourth, by making use of the method of North (1981) on normal A stars, one is able to obtain "differential" bolometric corrections for the Ap(Si) stars with respect to their normal counterparts in the cluster.

In summary, the objective of this study was to determine accurate absolute bolometric corrections for Ap(Si) stars. Many other fundamental stellar quantities of astrophysical interest are more easily obtained, and with higher accuracy, through the use of good bolometric corrections. In particular, comparison of Ap(Si) and normal stars in a "bolometric HR diagram" will provide much clearer insight into the evolutionary state of this class of Ap stars.

Program Description

There are three reasons why IUE data were used for this research. First, the data are calibrated to an *absolute* flux scale. The absolute fluxes provide a means for tying the photometrically constrained model fluxes to the absolute flux scale. Together, the model and observed fluxes provide a description of the flux distributions of the program stars which covers a wide enough wavelength range that the bolometric corrections can be determined reliably.

Second, the UV portion of the spectrum is where the flux is most strongly altered by the opacities being affected by the chemical peculiarities in the stars' atmospheres. The flux redistribution from the UV into the visible is the cause of the low luminosities registered for Ap stars for their anomalously blue colors. Knowledge of the flux in the UV is vital for understanding the distribution of the flux in the visible part of the spectrum.

Third, the flux for the program stars must be mapped over as wide a range of wavelength as possible. Significant flux levels were observed for Ap stars all through the range of IUE sensitivity.

Each of the program stars was observed with the SWP and the LWP camera in the low dispersion mode. The Ap stars selected for this study are Si-peculiar, or dominated by the Si peculiarity. Other types of Ap stars were excluded to reduce potential effects in the spectrum produced by weak companions typically associated with them. The program stars, both Ap and A normal, were all selected from stars classified by Abt and collaborators for the Coma Berenices cluster (Abt and Levato 1977), the Pleiades (Abt and Levato 1978), the α Persei cluster (Abt 1978), and IC 2602 (Abt and Morgan 1972). Classifications for IC 2602 were also taken from Whiteoak (1961).

The method employed by North (1981) and Lanz (1984) is a semi-empirical approach whereby the total flux distribution of a star is described by a combination of IUE fluxes and visible fluxes generated by model atmospheres. Geneva system magnitudes are used to constrain the flux predictions calculated from model atmospheres. Models by Kurucz (1979) and Muthsam (1978) were used in those studies. In this study models which are calculated by ATLAS9 (Kurucz 1990) were used.

The expression for the bolometric correction applicable to this study was derived by North (1981) from the definition of the bolometric correction,

$$\text{B.C.} = M_{bol} - M_v = m_{bol} - m_v = -2.5 \log \frac{\int_0^\infty F(\lambda) d\lambda}{\int_v F(\lambda) S_v(\lambda) d\lambda} - 0.08, \tag{1}$$

where $S_v(\lambda)$ is the response curve of the V bandpass. Assuming B.C.$_\odot$ = -0.08, a solar constant of $f = 1.360 \times 10^6$ erg cm^{-2} s^{-1}, and $m_{v\odot}$ = -26.74, one obtains the expression

$$\text{B.C.} = -2.5 \log \int_0^\infty F(\lambda) d\lambda - m_v - 11.49. \tag{2}$$

$F(\lambda)$ is given by the IUE fluxes observed between 1150Å and 3200Å and the fluxes from the models which best fit the Geneva photometry for wavelengths greater than 3200Å. Geneva magnitudes for the new Kurucz models will be generated with the method of North and Hauck (1979).

Results

Figure 1 shows the stars locations in BC vs. B2-G space. The triangles represent the Ap stars and the diamonds normal A stars. A freehand curve fit through the triangles and another through the upper envelope of diamonds are taken for the purposes of this report to represent the raw differences in bolometric corrections between the two groups of stars. The evolutionary states of the stars involved are not considered. The B2-G data used in the plot are de-reddened, as opposed to the colors listed in Table 1, which are not.

The free hand curves (not shown in Figure 1) indicate that the bolobmetric corrections between the two groups differ between 0.3 and 0.5 magnitudes in the range plotted. This is somewhat higher than found for field stars in North (1981) and Lanz (1984).

Table 1 Program Star Quantities

HD	Class	m_V	B2-G	T_{eff}	log g	log z	B.C.
			Coma Cluster				
108662	Ap(Si),(Sr,Cr)	5.4	-0.668	10000.0	4.5	1.0	-0.133
108945	Ap(Sr)	5.4	-0.483	8750.0	4.0	1.0	0.000
105805	A3 V	5.8	-0.515	8500.0	4.0	0.0	0.000
107966	A2 V	5.1	-0.562	8750.0	4.0	0.0	0.000
108382	A2 V	5.0	-0.559	8500.0	3.5	0.0	0.000
			Pleiades				
23387	Ap(Si,Cr)	8.2	-0.454	8750.0	4.5	1.0	-0.412
23642	Ap(Si)	6.8	-0.574	9750.0	4.5	1.0	-0.120
23964	Ap(Si,Cr)	6.7	-0.567	10000.0	4.5	1.0	-0.204
23568	B9 V	6.7	-0.615	10500.0	4.0	0.0	-0.246
23629	A0 V	8.1	-0.639	10000.0	4.0	0.0	-1.173
23632	A1 V	8.0	-0.620	9750.0	4.0	0.0	-0.569
24076	A2 V	6.8	-0.573	9500.0	4.5	0.0	-0.074
			IC 2602				
92664	Ap(Si)	5.8	-0.787	15000.0	3.0	1.0	-1.343
92536	B7 IV	6.6	-0.710	12000.0	4.5	0.0	-0.858
93549	B8 IV	5.4	-0.699	14000.0	4.5	0.0	-1.073
			α Persei				
19805	Ap(Si)	8.0	-0.500	9750.0	4.5	1.0	-0.168
22401	Ap(Si),(Sr,Cr)	7.6	-0.617	11000.0	4.0	1.0	-0.467
20391	A1 V	7.9	-0.523	9500.0	4.5	0.0	-0.074
21091	A0 V	7.3	-0.593	10500.0	4.0	0.0	-0.224
21279	B8 V	8.1	-0.574	11500.0	4.5	0.0	-0.887
21375	A1 V	8.3	-0.520	9750.0	4.5	0.0	-0.370
21398	B9 V	7.6	-0.614	11500.0	4.0	0.0	-0.595
21479	A1 V	7.5	-0.537	10000.0	4.5	0.0	-0.288

The basic objective, that being to generate semi-empirical flux distributions for the program stars, using IUE data, leading to the calculation of bolometric corrections, was accomplished. The comparison of the corrections for Ap stars with normal A stars in open clusters was also performed. Further theoretical implications will be considered in the paper to be written against the results presented in this final report.

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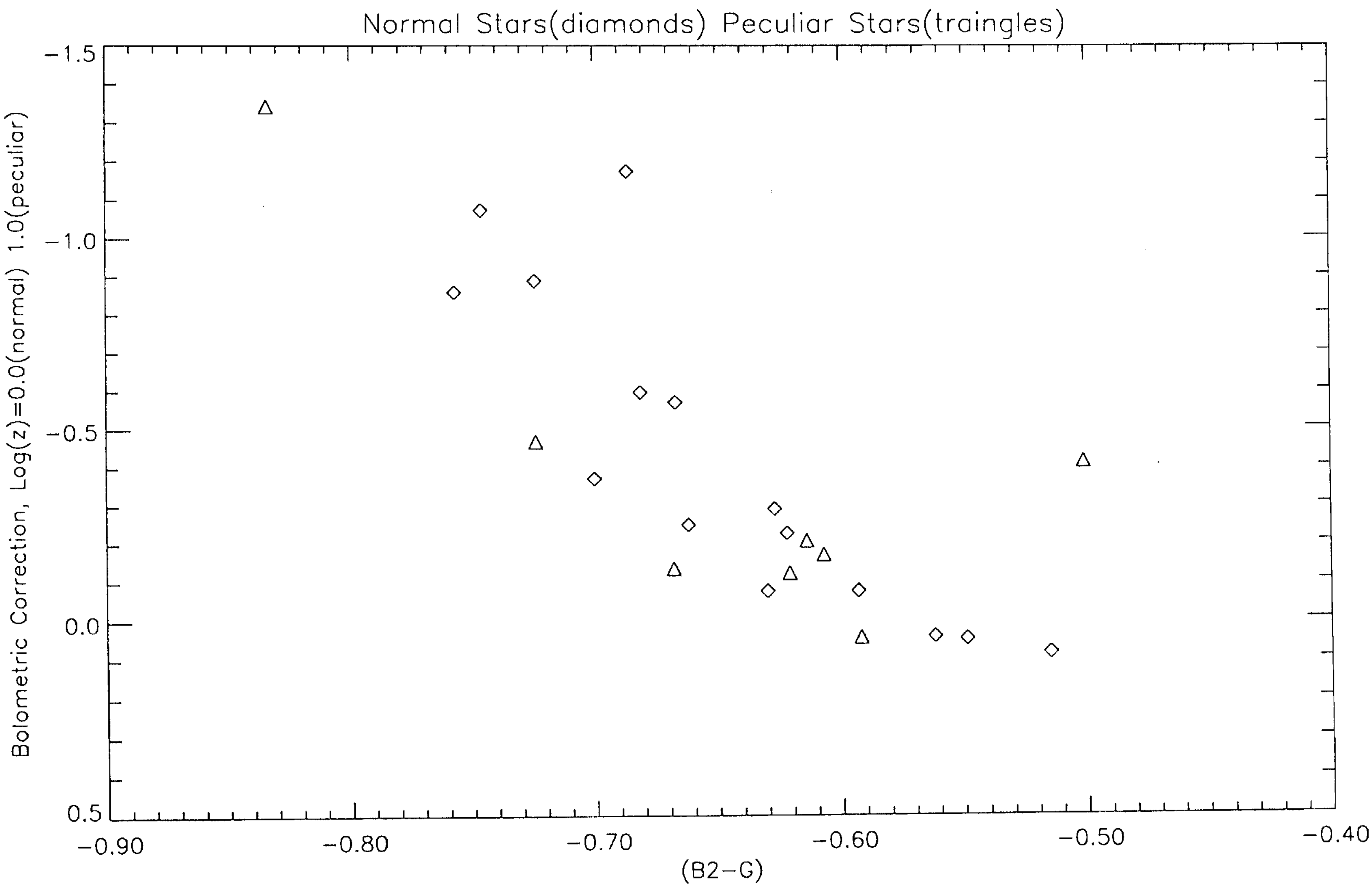
Figure 1


Normal Stars(diamonds) Peculiar Stars(traingles)
Bolometric Correction, Log(z)=0.0(normal) 1.0(peculiar)
(B2-G)
-1.5
-1.0
-0.5
0.0
0.5
-0.90
-0.80
-0.70
-0.60
-0.50
-0.40